THE U. S. PLANETARY PROGRAM

BY

DR. R. RHOADS STEPHENSON
DEPUTY DIRECTOR
TECHNOLOGY & APPLICATIONS PROGRAM
JET PROPULSION LABORATORY
MISSIONS IN FLIGHT

- VOYAGER
- GALILEO
- NEAR EARTH ASTEROID RENDEZVOUS (NEAR)
- MARS GLOBAL SURVEYOR
- MARS PATHFINDER
- CASSINI
- LUNAR PROSPECTOR
GALILEO EUROPAN MISSION (GEM) AND PRIME MISSION TOURS

END OF MISSION 31 DEC 99

START OF GEM

- Completed Prime Mission Orbits
- GEM Europa Campaign
- GEM Perijove Reduction Campaign
- GEM Io Campaign
### Galileo Europa Mission (GEM) Timeline

<table>
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<th>Year</th>
<th>January</th>
<th>February</th>
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**Events:**
- **Ice: Europa Campaign**
- **Water Study**
- **Torus Passages**
Near Earth Asteroid Rendezvous
CASSINI
INTERPLANETARY TRAJECTORY

VENUS SWINGBY
26 APR 1998

VENUS SWINGBY
24 JUN 1999

ORBIT OF
EARTH

DEEP SPACE
MANEUVER
3 DEC 1998

ORBIT OF
VENUS

EARTH SWINGBY
18 AUG 1999

LAUNCH
15 OCT 1997

ORBIT OF
JUPITER

JUPITER SWINGBY
30 DEC 2000

SATURN ARRIVAL
1 JUL 2004

PERIHELIA
27 MAR 1998 0.67 AU
29 JUN 1999 0.72 AU
CASSINI SCIENCE OBJECTIVES

MAGNETOSPHERE
1. CONFIGURATION AND CURRENT SYSTEMS
2. PARTICLE COMPOSITION, SOURCES AND SINKS
3. DYNAMICS OF THE MAGNETOSPHERE
4. INTERACTION WITH SOLAR WIND, SATELLITES AND RINGS
5. TITAN'S INTERACTION WITH SOLAR WIND AND MAGNETOSPHERE

SATURN
1. CLOUD PROPERTIES/ATMOSPHERIC COMPOSITION
2. WINDS AND TEMPERATURES
3. INTERNAL STRUCTURE AND ROTATION
4. SATURN'S IONOSPHERE
5. ORIGIN AND EVOLUTION OF SATURN

RINGS
1. STRUCTURE AND COMPOSITION
2. DYNAMICAL PROCESSES
3. INTERRELATION OF RINGS AND SATELLITES
4. DUST MICROMETEOROID ENVIRONMENT

TITAN
1. ATMOSPHERIC CONSTITUENT ABUNDANCES
2. DISTRIBUTIONS OF TRACE GASES AND AEROSOLS
3. WINDS AND TEMPERATURES
4. SURFACE STATE AND COMPOSITION
5. UPPER ATMOSPHERE

ICY SATELLITES
1. CHARACTERISTICS AND GEOLOGICAL HISTORIES
2. MECHANISMS OF SURFACE MODIFICATION
3. SURFACE COMPOSITION AND DISTRIBUTION
4. BULK COMPOSITION AND INTERNAL STRUCTURE
5. INTERACTION WITH MAGNETOSPHERE
ENTRY SPEED = 6.2 km/s

PEAK DECELERATION: 10g - 25g

INSTRUMENTS' INLET-PORT OPENED

DECELERATOR JETTISONED

METHANE CLOUD

ATMOSPHERIC SCIENCE EXPERIMENTS

MAIN CHUTE DEPLOYED

DROGUE CHUTE DEPLOYED

PROBE MAY PERFORM SURFACE SCIENCE

2.5 hours
Finding Water Ice

- Results from LP's NS shows lunar Hydrogen distribution.
- Most lunar Hydrogen comes from the solar wind, but...
- Hydrogen at the lunar poles, in permanently shaded craters, had to have another source.
- Based on cosmic abundance and chemistry statistics...
- The only logical conclusion is Hydrogen in the form of H$_2$O.
- 10 million to 300 million metric tons of ice crystals.

Plot of Hydrogen abundance over lunar surface. Note the consistent concentrations at North and South poles.

*Discovery is another first for Lunar Prospector.*
Getting Ready to Launch

Spacecraft and TLI during launch processing operations.
What Prospector does...

Lunar Prospector

Gamma Ray Spectrometer (GRS)
- Elemental abundance
- Distribution Maps
- Bulk composition of crust
- Approx. 18 in deep
- Origin and evolution of Moon

Doppler Gravity Experiment:
- Lunar gravity field
- Mass concentration (MASSCON) mapping

Alpha Particle Spectrometer / Neutron Spectrometer (APS/NS)

APS:
- Gas release events
- Lunar volcanic activity
- Lunar evolution

NS:
- Detects and quantifies Hydrogen
- Regolith maturity
- Search for lunar ice deposits

Magnetometer / Electron Reflectometer (MAG/ER)
- Lunar magnetic field
- Existence / sizing of lunar core
- Lunar structure and origin

Lunar Prospector launched on 6 January 1998 at 9:28 p.m. EST.
MISSIONS IN DEVELOPMENT

- NEW MILLENIUM DS-1 (COMET & ASTEROID FLYBY)
- MARS SURVEYOR (1998)
- NEW MILLENIUM DS-2 (MARS MICROPROBE PENETRATOR)
- STARDUST
- GENESIS
- MARS SURVEYOR 2001 & 2003
- MUSES-CN NANOROVER
- CONTOUR (COMET NUCLEUS TOUR)
- CHAMPOLLION/DS-4 (COMET LANDER & SAMPLE RETURN)
- MARS 2005 SAMPLE RETURN
- OUTER PLANETS/SOLAR PROBE
  - EUROPA ORBITER
  - PLUTO KUIPER EXPRESS
  - SOLAR PROBE
Deep Space One

DS1 Mission

- Validate the following prime technologies through space flight
  - Solar electric propulsion as primary propulsion
  - Advanced solar array
  - Autonomous navigation as primary navigation
  - Miniature imaging camera spectrometer

- Validate the following additional technologies through space flight:
  - Small deep-space transponder
  - Autonomy - remote agent architecture
  - Miniature ion and electron spectrometer
  - Autonomy - beacon monitor operations
  - Ka-band solid state power amplifier
  - Low power electronics experiment
  - Multi-functional structure
  - Power actuation and switching module
NSTAR Ion Thruster Operating on the DS1 Spacecraft During the "Thruster Compatibility Test"
New Millennium Program
MARS MICROPROBE

Separation Conditions:
Arrival date 12/2/99 - 12/15/99
Separation = 10 min. to Impact
Separation ΔV < 0.3 m/s
Entry velocity = 6.9 - 7.1 km/s
Flight path angle = -13.25° ± 0.4°

Entry Conditions:
Passive orientation
EDM mass ≤ 3.8 kg
Entry heating rate = 200 W/cm²
Max g < 20 deceleration

Landing Site:
-77° S, 230° W
Distance from spacecraft = 1.3 km

Forebody:
Max g < 30,000 deceleration
Penetration depth = 0.3 to 2 m
Primary Lifetime = 2 days

Atbody:
Max g < 80,000 deceleration
Penetration depth < 15 cm
Technology Demonstrations

Non-erosive, lightweight, single-stage atmospheric entry system

Microtelecommunications system with mixed digital/analog/RF ASICs

Power microelectronics with mixed digital/analog ASICs

Ultra low temperature lithium battery

Advanced 3D HDI microcontroller

Flexible interconnects for system cabling

Meteorological high-g pressure sensor

Soil conductivity high-g temperature sensor

Sample/water experiment
STARDUST, +X, -Y, +Z

- Aerogel
- High Gain Antenna
- Medium Gain Antenna
- Sample Return Capsule
- Navigation Camera
- Periscope
- Launch Vehicle Adapter
- Whipple Shields
Capturing "Bullets"
GENESIS

Spacecraft/SRC/Payload/Recovery

Spacecraft Bus

SRC

Payload

Lifting Chute Canopy

Suspension Lines

Mid-Air Retrieval

SRC
Mission Description

- Solar wind collection in halo orbit about L1 (23 mos.)
- Return leg (5 mos.)
- Outward Leg (3 mos.)
- Lunar Orbit
- Parking Orbit (optional)
- Positioning for Daylight Reentry

Millions of Kilometers
• Place a Spacecraft Outside the Earth’s Magnetosphere. Launch Aboard a Delta II in January 2001

• Expose Ultra-Pure Materials (Collectors/Concentrator)
  – Capture solar wind for two years
  – Solar wind ions and elements collected be above the “noise floor” of the collectors ⇒ clean collectors

• Return the Imbedded Solar Wind Samples to Earth. Sample Return August 2003 at Utah Test & Training Range

• Analyze the Samples With State-of-the-Art Laboratory Instruments
Mission Overview

- Integrated Space Science, Space Flight, and Life & Microgravity Sciences & Applications 2001 Mission
  - Orbiter
  - Long-Lived Lander with Rover
- Two Launches, Delta 7425
- Cost Constrained/Capabilities Driven Mission
  - Maintain Mars Surveyor Program Heritage
  - MSP '98 → MSP '01 → MSP '03
- Conduct Mars Science, Mars Environment, and Technology Experiments
Science Orbit Configuration (GRS Deployed)
Deployed Lander/Rover

Science Under Consideration:

Planetary Science
1. Rover with Camera & Instruments
2. Descent Imager Camera
3. Robotic Arm
4. Stereoscopic Imager

Human Exploration and Development of Space
5. Mars InSitu Propellant Production
6. Soil and Dust Experiment
7. Radiation Monitor

Educational Outreach
8. Student Nano-Rover
9. Greenhouse Experiment
10. Mars Long Duration Exposure Facility
MUSES-C/ CN Mission Overview

Cruise: 15 months
Solar electric propulsion
No Science Activities

Earth Return: 32 months
Solar electric propulsion
Three Nereus samples
No science activities
Mini-rover stays on Nereus

4660 Nereus (radius = 0.5 km)

Asteroid Operations: 4/6/03 - 5/30/03
MUSES-C: Nereus gravity mapping and remote science, sample collection
MUSES-CN: imaging, Near-IR point spectrometry, AXS (5/16/03 - 5/30/03)

Launch: Jan 7, 2002
M-5 Launch Vehicle
Kagoshima Space Center, Japan

Re-entry
V = 22.6 km/sec
Spin-stabilized
h = 200 km

Ranges for Key Mission Events (AU)

<table>
<thead>
<tr>
<th>Event</th>
<th>Sun-S/C</th>
<th>Earth-S/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch</td>
<td>0.98</td>
<td>0.00</td>
</tr>
<tr>
<td>Cruise (max)</td>
<td>2.02</td>
<td>2.97</td>
</tr>
<tr>
<td>Arrival</td>
<td>1.85</td>
<td>2.61</td>
</tr>
<tr>
<td>Departure</td>
<td>1.86</td>
<td>2.05</td>
</tr>
<tr>
<td>Return (max)</td>
<td>2.38</td>
<td>3.34</td>
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SSW 2/17/98
MUSES-CN Rev 0 Rover

- Panoramic imaging at 1 mrad/pixel in 8 vis/VNIR spectral bands,
- Microscopic imaging at < 10 microns/pixel in those same bands
- NIR spectrometry from 1.2 to 2.2 microns at ~20 nanometer resolution
- Sojourner Like AXS
- Body articulation allows "hopping" in 10μG environment and "posing" of instruments
- Comm relay to MUSES C
- Development process modelled after Sojourner (and many of same team):
  - Software Development Model evolves into Engineering Model as SW workalikes are replaced with flight-likes
  - Build a protoflight unit/flight spare (SIM) and a Flight Unit Rover (FUR)
  - "Sojourner Like" Product Assurance
- 30 month PDR to Ship

four 6.5cm dia wheels on 7 cm articulated struts,
Power ~3 watts; 14 x 14 x 6 cm; 1250 g
**Comet Nucleus Tour—CONTOUR**

A Mission to Study the Diversity of Comet Nuclei

<table>
<thead>
<tr>
<th>Encounter Date</th>
<th>Sun Distance (AU)</th>
<th>Earth Distance (AU)</th>
<th>Phase Angle (deg)</th>
<th>Flyby Speed (km/s)</th>
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<tbody>
<tr>
<td>Encke, Nov 12, 2003</td>
<td>1.07</td>
<td>0.27</td>
<td>12</td>
<td>28.2</td>
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<tr>
<td>SW3, Jun 18, 2006</td>
<td>0.95</td>
<td>0.33</td>
<td>100</td>
<td>14.0</td>
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<tr>
<td>d’Arrest, Aug 16, 2008</td>
<td>1.35</td>
<td>0.36</td>
<td>68</td>
<td>11.8</td>
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</tbody>
</table>

- All encounters occur near maximum comet activity and at time of excellent viewing from Earth.
- First encounter (Encke) occurs only 15 months after launch. All three comets visited within 5 years.
- Possibility of extended mission to provide second look at Encke.
- High probability of encountering a “new comet.”
CONTOUR

Comet Nucleus Tour—CONTOUR

- **Mission Concept:** Uses Earth gravity-assist maneuvers to accomplish multiple cometary encounters
- **Target Selection:** Emphasis on diversity and unique objects.
- **Small, focused science payload**
  - High-Resolution Imager/Mapping Spectrometer (CRISP)
  - Wide-Angle Imager (CFI)
  - Dust Analyzer/Counter (CIDA)
  - Neutral/Ion Mass Spectrometer (NGIMS)
- **Simple, robust spacecraft**
- **Launch Vehicle:** Delta-7425 (Med-Lite)
Deep Space 4 / Champollion
Key Technology Developments

Precision Guidance for Landing and Docking
Sample Return
Micro Electronics and Software
In-Situ Analysis Instruments
Sample Acquisition and Transfer
Autonomous Docking
Advanced Solar Electric Propulsion
Inflatable Rigidizable Solar Array
Comet Tempel 1 Sample Return
(Delta 2 7925)

30 day tics on spacecraft path

Tempel 1

Coast

Earth

Launch 4-23-03

Comet Departure 4-23-06

Earth Return 5-31-10
$V_{HP} = 10.21$ km/s

Comet Rendezvous 12-2-05
142 days stay time

$C_3 = 5.8$ km$^2$/s$^2$
Flight time = 7.1 years
Minj = 1066 kg
$M_{xenon} = 400$ kg
$M_{SIC, net} = 666$ kg
$M_{LVA} = 15$ kg
Available Power @ 1 AU = 11 KW
Monoprop $\Delta V = 50$ m/s
Cold gas $\Delta V = 10$ m/s
Ventry at Earth = 15.13 km/s
Mars Sample Return
Baseline Spacecraft Configuration
Reference Trajectory Characteristics

Earth Launch (5-Nov-04)

Mars Departure (21-Jul-07)

Earth Return (29-Apr-08)

Mars Arrival (1-Feb-07)

View from Ecliptic North Pole
1-Month Tick Marks

Mars at Earth Launch

Page 16 (12-Feb-98)
SCIENCE OBJECTIVES

- Determine the presence or absence of a subsurface ocean
- Characterize the three-dimensional distribution of subsurface liquid water and its overlying ice layers
- Characterize the morphology of the surface and identify sites of recent or current activity

INVESTIGATIONS

- Precision gravity field determination
- Laser Altimetry
- Ice-penetrating radar
- Imaging

LAUNCH - TRAJECTORY OPTIONS

<table>
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<tr>
<th>Launch Date</th>
<th>Direct</th>
<th>VVVGA</th>
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<tbody>
<tr>
<td>Launch Date</td>
<td>Nov. '03</td>
<td>Aug. '04</td>
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<tr>
<td>Flight Time to Jupiter (yrs.)</td>
<td>3.0</td>
<td>~7.0</td>
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<tr>
<td>Launch System</td>
<td>STS/US/ Star 48</td>
<td>Delta 7925H/ Star 30C</td>
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MISSION: IUS utilization discussions with Boeing, USAF

DESIGN STATUS

TECHNOLOGY: X2000 avionics under development. Propulsion system mass reduction is critical. Radar development proposed via PIDDP.

SDT: Chris Chyba, chair. Cat 1A objectives established.

MASS BREAKDOWN:

- Science: 20 kg
- Spacecraft: 109 kg
- Rad shielding: 27 kg
- Adapter+Conting.: 102 kg
- Propulsion System: 111 kg
- Propellant: 553 kg

DS/SCB 980204
**SCIENCE OBJECTIVES**

Pluto and Charon:
- Characterize surface geology and morphology.
- Surface composition mapping.
- Characterize neutral atmosphere structure and composition.

Possible Extended Mission:
- > 1 Kuiper Disk object flyby.

**INVESTIGATION**

- Imaging
- IR Mapping Spectrometry
- UV Spectrometry
- Radio Science Uplink Occultation

**LAUNCH - TRAJECTORY OPTIONS**

<table>
<thead>
<tr>
<th>Launch Date</th>
<th>Launch System</th>
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<td>Nov 03, Nov 03</td>
<td>Delta 7925H/Star 30C</td>
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<td>Dec 04, Dec 04</td>
<td>STS/IUS/Star 48</td>
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<tr>
<td>Feb 03, Feb 03</td>
<td>STS/IUS/Star 48/Star 30</td>
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</table>

**DESIGN STATUS**

- **MASS:**
  - Science: 7 kg
  - Spacecraft: 95 kg
  - Adapter+ Conting: 50 kg
  - Propulsion System: 24 kg
  - Propellant: 37 kg

- **TECHNOLOGY:**
  - X2000 Avionics development.
  - Breadboard payload pkg developed.

- **SDT:**
  - J. Lunine, chair. Cat 1A objectives established.
SCIENCE OBJECTIVES

- Determine the mechanisms that accelerate the solar wind.
- Find the source and trace the flow of energy that heats the million degree corona.
- Determine the three-dimensional structure of the inner corona above the polar regions and the equatorial belt.
- Map the configuration and state of the magnetic field, and the pattern of the surface and subsurface flows from pole to pole.
- Find the origin of the fast and slow solar wind near the surface of the sun.

INVESTIGATIONS

- Integrated Fields + Particles (magnetometer, plasma wave, plasma/particles sensors)
- Remote Sensing (EUV imager, Vis/X-ray magnetograph, all-sky coronal imager)

LAUNCH - TRAJECTORY OPTIONS

<table>
<thead>
<tr>
<th>Launch Date</th>
<th>Flight Time (yrs)</th>
<th>Launch System</th>
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<td>JGA (Retrograde)</td>
<td>Nov '03 Every 13 mos.</td>
<td>Delta III / Star 48V</td>
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<tr>
<td>ΔV-EJGA (Retrograde)</td>
<td>Dec '03 Every 13 mos.</td>
<td>Delta 7925H / kickstage</td>
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MASS:
- Science 15 kg
- Spacecraft 126 kg
- Adapter, Contingency 59 kg
- Propulsion System 27 kg
- Propellant 32 kg

TECHNOLOGY: X2000 avionics development underway. Thermal shield and solar arrays are critical unique items that are not presently supported. Integrated instrument package development required.

SDT: George Gloeckler, chair. Cat 1A objectives established
BEYOND THE SOLAR SYSTEM
(PLANETARY EXPLORATION IN OTHER SOLAR SYSTEMS)

- NEW MILLENIUM DS-3: FORMATION FLYING INTERFEROMETER
- SPACE INTERFEROMETRY MISSION (SIM)
- INTERSTELLAR TRAVEL
Space Interferometry Mission

- 10-m Optical Interferometer
- Astrometry
  - 4 μas global
  - 1 μas narrow angle
- Imaging
  - 10 mas
  - $10^{-4}$ starlight nulling

- Looking at the Universe with μ arcsecond precision shows subtleties in the Universe never before detectable
Microarcsecond Precision Opens a New Window to a Multitude of Phenomena Observable with SIM

- Reflex motion of Sun from 100 pc
- Parallactic Displacement of Galactic Center (150 μas)
- SIM Positional Error Circle 4 μas
- Hipparcos Positional Error Circle (0.64 mas)
- HST Positional Error Circle (~1.5 mas)
- Relativistic Displacement of Distant Star due to Jupiter (100 μas)
Scale Of The Heliosphere and Local Interstellar Medium

Solar System

- Sun (☉)
- O (Other)
- Earth (Earth)
- Asteroid Belt

Kuiper Belt
~ 10^8 Comets

Oort Cloud
~ 10^12 Comets

Alpha Centauri

Termination Shock
Heliopause

Dense Clumps?

Edge of Local Cloud?

Bow Shock

Heliosphere
Interstellar Medium

R (AU)

10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}

After Richard Mewaldt, Caltech, 19982
Ambitious Future Missions are More Propulsively Demanding

Candidate Missions Under Consideration in On-Going JPL Studies of Interstellar and Interstellar Precursor Flights

- 4.5 LY Interstellar (7,120 AU/Yr, 40 Yrs, 1 MT)
- 1 LY Oort Cloud (1,580 AU/Yr, 40 Yrs, 1 MT)
- Heliopause Explorer (200 AU/Yr, 50 Yrs, 1 MT)
- TTAU (25 AU/Yr, 40 Yrs, 1 MT)
- 550 AU Galactic Lens (27.5 AU/Yr, 20 Yrs, 0.5 MT)
- 100 AU Solar Polar (10 AU/Yr, 10 Yrs, 0.5 MT)
- Total Human Energy Production for 1 Day
- 1 M-Ton H Bomb
- Saturn V 1st Stage

Payload Kinetic Energy (Joules)

Time Until Launch
### Preliminary Evaluation Results

<table>
<thead>
<tr>
<th>CONCEPT</th>
<th>ΔV CAPABILITY</th>
<th>INFRASTRUCTURE REQUIREMENTS</th>
<th>TECHNOLOGY REQUIREMENTS</th>
<th>CANDIDATES</th>
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<td>Advanced EP</td>
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<td>Insufficient ΔV Not Yet Evaluated</td>
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<td>- On-board power</td>
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<td>- Beamed power</td>
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<td>Fission Fragment</td>
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<td>Fusion</td>
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<td>- ICF / MCF</td>
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<td>- Antimatter Catalyzed</td>
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<td>- Interstellar Ramjet</td>
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<td>Matter-Antimatter Annihilation</td>
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<td>Light Sails (Laser, m-wave)</td>
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<td>Relativistic Particle Beam / Magnetic Sail</td>
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<td>Ultra-Light Solar Sail</td>
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<tr>
<td>EM Catapults</td>
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CANDIDATE PROPULSION SYSTEMS FOR INTERSTELLAR MISSIONS

FISSION
Fission Fragment
"Rocket" "Sail"

FUSSION
Inertial / Magnetic Confinement Fusion (ICF / MCF)
Daedalus ICF

MATTER-ANTIMATTER
Beam-Core Antimatter Rocket

BEAMED MOMENTUM SAILS
Laser Lightsail
Relativistic Particle Beam / MagSail

COMBINATIONS
Antiproton-Catalyzed Fission / Fusion
Bussard Interstellar Ramjet (Fusion)

ADVANCED ELECTRIC PROPULSION
EM Catapult
Micro-Spacecraft

ELECTROMAGNETIC CATAPULTS
Linear Accelerator
DS3: NEW MILLENNIUM INTERFEROMETER

- Space optical interferometer
  - 100m to 1km baselines
  - 1 to 0.1 milliarcsec resolution
- 3 separated spacecraft
- Early 2002 launch
- Heliocentric orbit
- 6 month mission
Baseline Configuration

- 3 Spacecraft Formation Flying with 2-D aperture synthesis
- 100-1000 m baseline